Is there a galactic component for the ultra high energy cosmic rays?

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Under the hypothesis that Gamma Ray Burst (GRB) might be responsible for the origin of Ultra High Energy Cosmic Ray (UHECR), we propose a two component (galactic and extra-galactic) model for the UHECR origin. The model is based on two facts. The first is the anisotropies found in the angular distribution of GRBs from BATSE catalog. Second is that, of all the located long-GRBs, only approximately 15 percent of them have their spectroscopic redshift determined, and some 38 percent of them have a x-ray, optical, or radio afterglow. So far, in short-GRBs, no afterglow and no red shift have been detected, suggesting that these GRB sources are inside or close to our Galaxy. This two component model for the UHECR is further supported by the experimental evidences of an UHECR excess around 10^{18} eV from the direction of the galactic central region. The model offers in a natural way an explanation for the presence of cosmic rays with energies beyond the Greisen-Zatsepin-Kuz'min (GZK) cutoff.

1. INTRODUCTION

After the discovery of the Microwave Background Radiation (MBR), that fills the universe as a sea of photons, with a mean temperature of 2.7 K at present epoch, Greisen [1] and Zatsepin and Kuz'min [2] independently pointed out that the MBR would make the universe opaque to UHECR particles with energies approximately 5×10^{19} eV and above. This hypothesis is well accepted and is known as the GZK cutoff. So far, observational data of several experiments about UHECR have report events with energies beyond the GZK cutoff [3, 4, 5]. In addition, the present data show strong discrepancies in the UHECR energy spectrum. On one side, the AGASA (extensive air shower) experiment claims a spectrum beyond the GZK cutoff, without any evidence of the GZK cutoff, on the other side the HIRES (air fluorescence) experiment is in agreement with the expected universal distribution of sources and showing the GZK cutoff in the energy spectrum. This means at least that there is a systematic error, probably in the energy determination, in one of the experiments. However, this discrepancy can also be attributed to latitude effects, due to the limited coverage of the sky by experiments located in the northern hemisphere. So far only experiments with a full (SUGAR experiment [6]) or partial (AGASA experiment [7]) coverage of the galactic central region have reported a cosmic ray excess in the energy region of approximately 10^{18} eV in the direction of the galactic center. The accumulating data from AUGER (extensive air shower plus air fluorescence) experiment [8], whose southern part is now in progress, on the basis of a larger data set will tell us which is the correct alternative in the near future.

In the past years, there are some surveys about a statistical correlation between UHECR events and compact sources at high redshift. Depending on the data set, in some cases a positive correlation has been reported [9], but there are also negative results [10]. The identification of compact objects like BL Lac or quasars at high redshift as UHECR sources reinforces a cosmological origin, and has taken to formulate new scenarios such as the violation of the Lorentz invariance [11] as responsible for the propagation of ultra high energy cosmic ray with energies above the GZK cutoff. In addition to the top-down models [12], where the collapse or decay of super-massive particles like magnetic monopoles, superconducting strings, as well as the ν Z burts [13] inside a volume with a radius less than 50 MPc from the Earth can explain the UHECR data above the GZK cutoff.

The hypothesis that Gamma Ray Burst (GRB) might be responsible for the origin of UHECR has been suggest earlier [14]. The GRBs are probably the most powerfully events in the universe, and it is believed that protons can be accelerate in a GRB by internal shocks taking place in a collimated jet direction. The GRBs have been observed in spacecraft experiments as short flashes of gamma rays that outshine the rest of the entire gamma-ray sky at a rate of around one event per day [15], mostly in the energy band of KeV to MeV . The first measurements of the redshifts in GRB afterglows [16], together with the highly isotropic distribution of their arrival directions, have established a cosmological origin for them. The association of GRBs and UHECRs is further supported by the similarity of energy generation rates. the average rate of gamma-ray energy emitted by GRBs is comparable to the energy generation rate of UHECRs. In addition, the almost isotropic distribution of the arrival directions of UHECR and GRBs is also an ingredient in favor of an association between them.

The main constraint on the association between GRB and UHECR is that UHECR events above the GZK cutoff require only GRBs inside a volume of radius less than 50 Mpc from the Earth can contribute to the UHECR flux. What is the expected rate of GRBs in this volume? A pessimistic answer on the basis of only cosmological origin to the GRBs gives an estimative of about one GRB per 100 years. On the other hand, from an optimistic point of view, statistical surveys have shown that it is not always possible to spectroscopically determine the red shift even in some

long well located GRBs accompanied by x-ray, optical and radio afterglow. A plausible explanation for these results is the assumption of a local origin. That is to say, they are close to our Galaxy or inside it. Around 70 percent of the observed GRBs are the long-soft type with approximately 30 s duration. Some of these bursts have their measured red shifts clustering in $z \sim 1$, consequently they have a cosmological origin and they are connected with supernovae events. There is also another category of GRBs, the short-hard type with approximately 0.2 s duration, where no red shift and no afterglow have been detected from these bursts. Probably these short bursts result from a different engine than long bursts, they could be connected with compact binary mergers, like two neutron stars or with a black hole component, as well as binary pulsar. They are expected at a high rate of 2×10^{-4} per year in a galaxy like the Milk Way [17]. These characteristics suggest the Two Component Model (TCM), galactic and extra-galactic for the origin of the GRBs.

Another characteristic that strongly support the TCM for the GRBs origin is their isotropic distribution of the arrival direction. They are regarded to have a uniform distribution in galactic coordinates. A more accurate analysis of the angular distribution of GRB shows some deviations from a simple isotropic distribution [18]. Under certain assumptions such as an Euclidean space and standard candle GRBs, the formulation of the TCM is plausible. Here we make an extension of these assumptions to the UHECR events. We point out here that a TCM for the UHECR is further supported by the experimental evidences of a UHECR particle excess around 10^{18} eV energies from the direction of the galactic central region.

2. THE SEELIGER'S THEOREM AND GRBS

A consequence of the Seeliger's theorem is the following. If sources are uniformly distributed in a spherical volume V of radius r, and have fixed brightness, then the flux $S(E)$ obtained from a source is proportional to r^{-2}, while the number N of sources observed down to a given flux limit is proportional to r^3

$$N \propto S(E)^{-3/2} \tag{1}$$

This relation has been observed in radioastronomy as the $\log N \to \log S(E)$ plot

$$\log N \propto -\beta \log S(E) \tag{2}$$

where $\beta = 3/2$ provided that the sources are homogeneously distributed in an Euclidian space. Then, if a true deviation from this value eventually takes place, we will have the evidence that the space is non-Euclidian or/and the sources are inhomogeneously distributed.

The black line in Fig.1 shows the $\log N \to \log S(E)$ plot obtained for the GRBs on the basis of 2704 burst from BATSE catalog. We can see from this figure that a simple $\beta = 3/2$ (blue line) does not fit the data. This means that the spatial distribution of GRBs is not consistent with a homogeneous case. As already has been commented, a possible interpretation for this result is to invoke a non-Euclidian space. However, another alternative is to introduce a second population of GRBs with a gaussian distribution that reflects the radial distribution of matter in the galaxy and its surrounding halo. The fluencies of the observed GRBs between 10^{-5} to 10^{-7} erg/cm^2 imply isotropic burst energies up to approximately 4×10^{54} erg. While taking beaming angle corrections of about 5 degrees into account, it is expected a narrow distribution around 5×10^{50} erg. Here, we assume the same value as in [18] that gives 10^{51} erg to the gaussian peak which corresponds to a mean flux of 2.8. The best fit is obtained for an amplitude of about 7.5 percent of the first component and a r.m.s. value of 13.4. In short, the TCM spatial burst distribution is given by the following cumulutive function

$$N(> S) = 950 S^{-1.5} + 70 e^{[-(S-2.8)/19]^2}. \tag{3}$$

The red line in Fig.xx represent this function.

3. THE EXTENSION TO THE UHECR

Under the assumption of an association between GRBs and UHECR, the hypothesis of a second population of GRBs of galactic origin implies also the existence of UHECR of galactic origin. Due to the small statistics, especially in the energy region above the GZK cutoff, it is still not possible to mount the log N $\to$ log S(E) plot, only on the basis of UHECR data. Consequently, we make a calibration to obtain the TCM UHECR distribution on the basis of the TCM GRBs distribution.

The detection of an excess of cosmic ray from the direction of the galactic center region observed by AGASA and SUGAR in the energy range of 10^{18} eV opens the door to the possibility that UHECR above the GZK might be

created also in our Galaxy. We assume that the excess of cosmic ray from the direction of the galactic center in the energy range of 10^{18} eV corresponds to the peak of a gaussian distribution and represent the second population of the UHECR. This assumption permits us to make a calibration between the GRB flux and the energy of the UHECR. The other parameters of this second population distribution of UHECR are the same as the GRBs distribution. Figure 2 summarizes the situation where the cumulative distributions for UHECR and for three different energies in the peak of the gaussian distribution are shown. It is possible to see that the contribution of the second population to the UHECR flux around the GZK cutoff is sensitive to the value of the gaussian peak. The comparison of the predictions of the TCM and the experimental data is shown in Fig.3.

4. CONCLUSIONS

Under the assumption that GRBs might be responsible for the origin of UHECR, we have presented here an extension of the Two Component Model of GRBs (galactic, and extra-galactic) to explain the origin of UHECR. The inclusion of a local galactic source for the UHECR origin is further supported by the experimental evidences of an UHECR excess around 10^{18} eV from the direction of the galactic center region. This excess can be considered as the peak of a gaussian distribution of the second component and permits us to make a calibration among the GRB flux and the UHECR energies.

Perhaps the main constraint to the TCM is, if the UHECR sources are close, why the arrival direction of the events does not point toward their sources? So far, the UHECR distribution does not follow the galactic star distribution. This means that probably its surrounding diffuse halo and even the local distribution of galaxies can lodge UHECR sources. UHECR event rates beyond the GZK cutoff as observed by AGASA experiment can be linked at least in part to GRBs of short-hard type, because these GRBs neither have afterglows nor redshift suggesting that some of these GRBs sources are close to or inside of our galaxy. These results are in agreement with others surveys [19], showing that GRBs with time duration below 100 ms appear to form a separate class of GRBs, because from their asymmetry plot the events appear to originate nearby within the Galaxy.

The short-hard GRBs probably are formed for instance by coalescence of corotating binary neutron star systems. This process is dominated by a strong magnetic field. Thus, magnetic deflections of the UHECR in the first stages of their propagation can be responsible of a arrival direction of events without pointing toward their sources.

We are waiting for the next round of the AUGER experiment. Certainly only after a large set of data that we can confirm or refute the TCM for the origin of UHECR.

5. ACKNOWLEDMENTS

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[19] D. B. Cline et al., astro-ph/050309 v1.

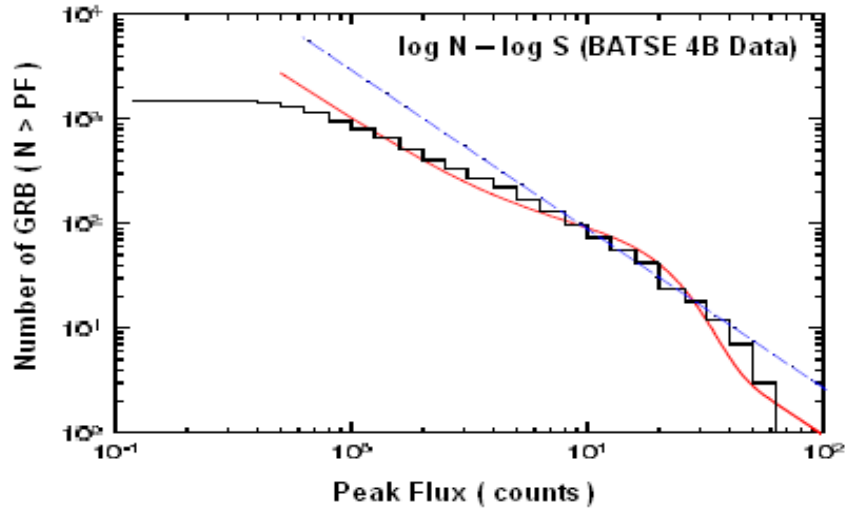FIG. 1: The $\log N \to \log S(E)$ plot. Black line: GRBs distribution on the basis of 2704 burst from BATSE catalog. Blue line: Uniform distribution. Red line: Uniform distribution plus gaussian distribution (Two component model)
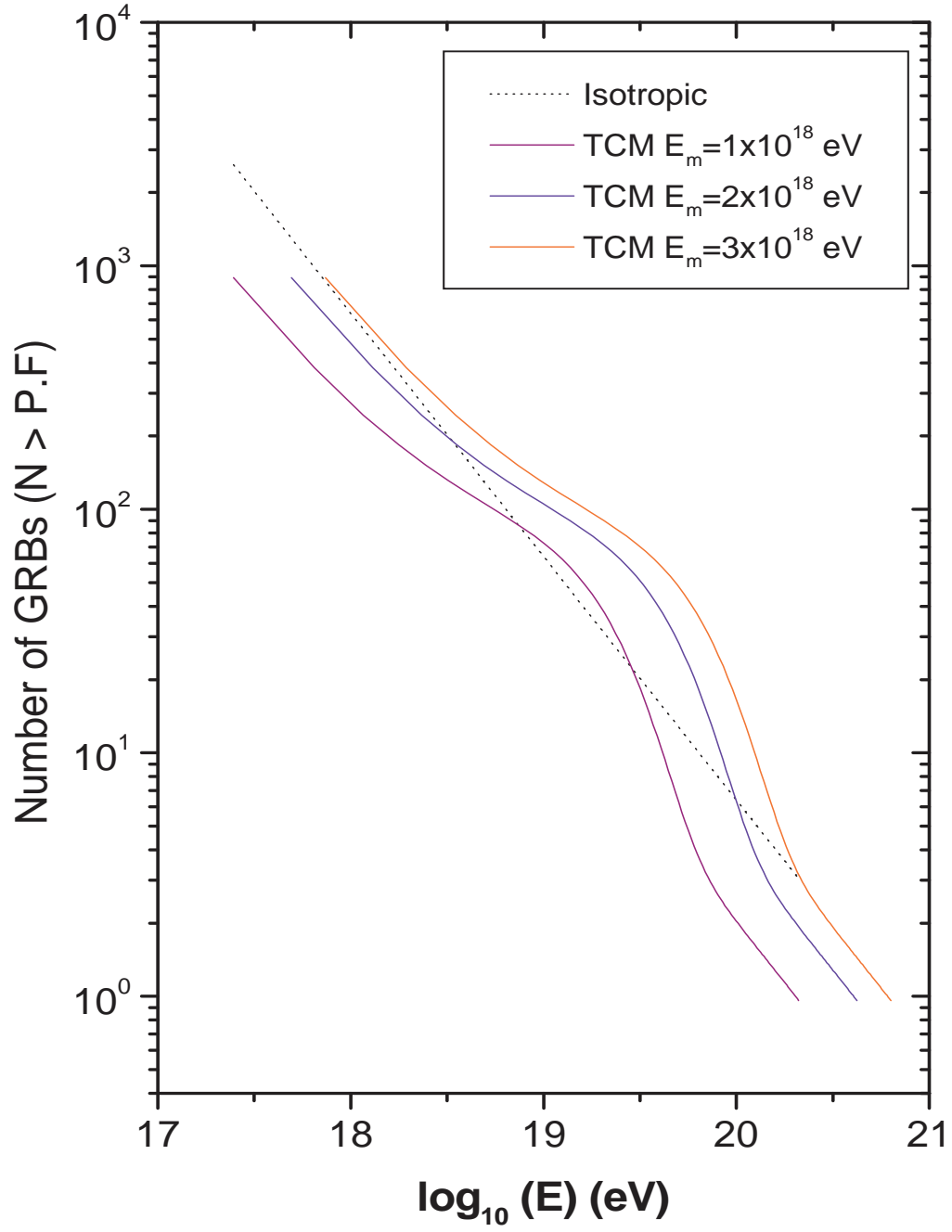
FIG. 2: Two component model cumulative distribution for UHECR (one by one association with GRBs) and for three different energies in the peak of the gaussian distribution
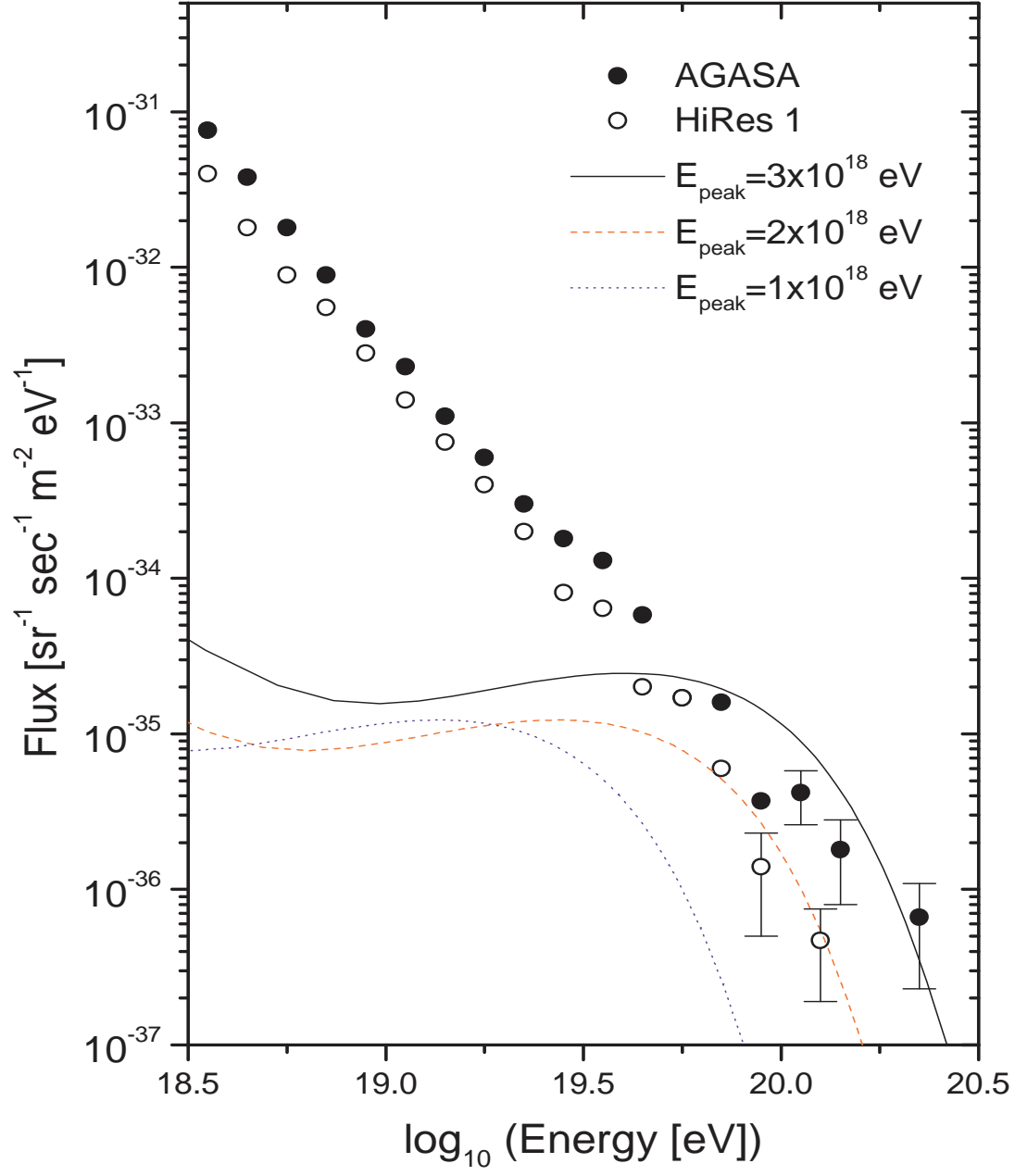
FIG. 3: Comparison between the Two Component Model and experimental data